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Electronic Regulation in Solar Photovoltaic Systems: Types, Functionality and Design Aspects

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ABSTRACT
This paper discusses the electronic regulation in solar photovoltaic (SPV) systems and highlights the importance of charge regulation between the SPV array & battery bank to reduce mismatch losses. The merits of charge regulators such as self-regulators, series regulators, shunt regulators and monolithic regulators for their suitability in field conditions is reviewed. The paper brings into sharp focus the requirement of a charge regulator which is capable of tolerating the changes in battery temperature. The design aspects of such a regulator are presented thereafter. The explicit feature of the proposed design for the charge controller will be float voltage adjustment and automatic cut off of the battery from rest of the circuitry in case of the abnormal increase in temperature of the battery. The application of the proposed charge regulator in solar lighting system is also discussed.
Keywords - Battery bank, charge regulation, float voltage, microcontroller, SPV system

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I. Introduction

Electricity crisis is a major problem in the present global scenario. This problem is even more pronounced in densely populated developing countries. In many areas the limited supply of electricity is not able to fulfil the basic demand of people from those areas. A viable solution to this problem is electricity generation using solar photovoltaic (SPV) system. The core of the SPV system is an array of PV modules which convert sunlight into electricity. The output of the array is variable D.C. A stand-alone PV system works entirely on its own. It is independent of the electricity grid. Therefore, they are useful in those areas which are either not easily accessible or not connected to utility grid. To power loads continuously throughout the day even when the sun is not shining, batteries are incorporated for energy storage. Fig. 1 presents the block diagram of a typical stand-alone SPV system. Applications of battery based standalone PV system include street lighting, traffic control systems, communication systems in rural areas etc. Therefore, the functional circuit of the solar PV system essentially comprises of conversion, storage and load consumption devices [1],[2].

In SPV power supply, an optimum load is required by the PV array into which it can deliver its maximum power [3]. But this requirement of optimum load varies with the availability of solar radiations and ambient temperature. The battery in turn offers a load to the PV array. This load also varies with the state of charge and temperature of the battery. Therefore, an optimally matched interconnection of these power system components under all conditions is very difficult to achieve in normal practice. The mismatches of different SPV system components hinders the optimum sizing of the system, resulting in loss of energy and degradation of components [4]-[6]. Therefore, to enable the system to maintain optimal management of energy flow within the system, regulation devices are needed.

This paper reviews charge regulation and discusses the merits of charge regulators such as self-regulators, series regulators, shunt regulators and monolithic regulators for their suitability in field conditions. The design aspects of a charge regulator capable of tolerating the changes in battery temperature are presented thereafter. The applications of the proposed charge regulator are also discussed.

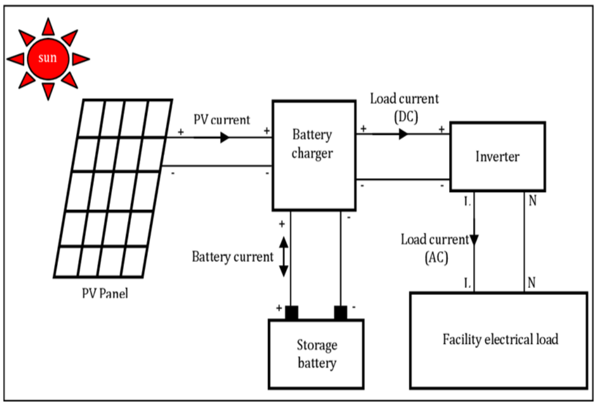

Figure 1: Block dig of a typical stand-alone SPV Power System **[7]**.

II. Functioning of charge controller

Battery is a vital and expensive component of SPV system. Overcharging and deep discharging of the battery reduces its lifespan. Charge controller plays a vital role in protecting the battery [8],[9]. It regulates the energy flow between the array and the battery. These devices prevent excessive charging of the batteries when the array produces more electricity than the batteries can store. Also, if the batteries state of charge is too low, charge controller prevents them from supplying electricity. Without charge controllers, battery undergo extreme wear and tear which degrades its performance and lifetime, and possibly even short circuit [10].

In a common stand-alone SPV system, a charge controller floating operating condition occurs when the battery voltage fluctuates between maximum (100%) and minimum (often taken 60 – 70%) state of charge (SOC) of the battery. In such a case, system is autoregulated during the day and the regulation makes use of simple protection diode which protects PV module from discharge of battery during night.

The overcharge and over discharge conditions occur where the battery voltage reaches some critical values (V_{max} and V_{min}). In that case the regulator is characterized by two functions:

a) Collecting information on state of charge (SOC) of the battery, (battery voltage V_B)

b) Knowing the constraints V_{min} and V_{max}

The controlling program can be summarized as follows:

If $V_B > V_{max}$: Disconnect battery from PV array.

If $V_B > V_{max}$ and $V_B < V_{H1}$: Reconnect it with array. ($V_{max} – V_{H1}$) gives hysteresis voltage.

If $V_B < V_{min}$: Disconnect battery from load.

If $V_B < V_{min}$ and $V_B > V_{H2}$: Reconnect battery to load. ($V_{min} – V_{H2}$) gives hysteresis voltage.

III. Types of regulators

Many regulators with variable technical sophistication are known, which are discussed below:

3.1 Self-regulator

Self-regulation doesn't employ a separate regulator but relies on the fact that as the battery voltage increases, the current available from a PV panel connected in parallel with the battery will decrease [3]. This can be seen from the typical I-V graph of a solar PV module, given in Fig. 2. This type of regulation work only if the load, the solar insolation and module temperature all experience very little variation.

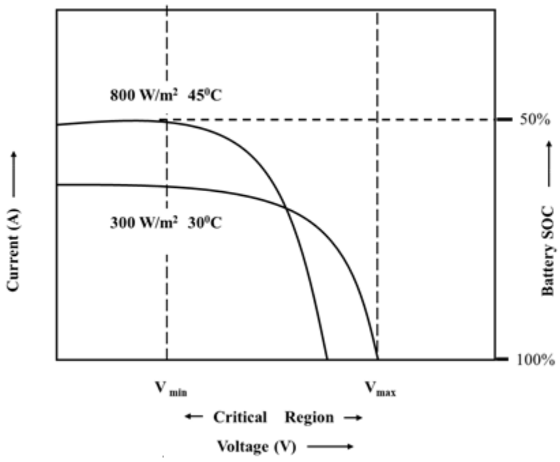

Figure 2: I-V graph of SPV array, showing self-regulation.

3.2 Series regulator

A series regulator interrupts the charging current by open-circuiting the PV array. The control element is in series with PV array and battery [11]. This type of regulator doesn't allow reduced currents as voltage rises and hence is not optimum charging.

3.3 Shunt regulator

When the voltage reaches a certain level, shunt regulator turns on and current is diverted through the shunt. During shunting of the solar array, heat dissipates and a large heat sink is required to dissipate the excess current [12]. Since shunt dissipates power from module, it is used for small systems producing 30 Amperes or less, where shunt can handle power flows.

3.4 Monolithic or IC Voltage regulator

The voltage regulator fabricated on a single silicon chip is known as Monolithic or IC voltage regulator. The circuit of the monolithic regulator consists of a built-in reference voltage source, feedback network, series transistor, current limiting and thermal shutdown provisions. The monolithic regulators are available for 5,6,8,10,12,15 and 24V output. The monolithic regulators are also available with variable output voltage, positive or negative voltage.

IV. Proposed Design

The block diagram of the proposed charge controller is given in Fig. 3. The explicit feature of the proposed design for the charge controller will be float voltage adjustment and automatic cut off of the battery from rest of the circuitry in case of the abnormal increase in temperature of the battery. Such situation of abnormal high temperature of battery can arise e.g., because of the corrosion of the terminals of the battery in which the terminal voltage doesn't increase but charging continues which heats the battery beyond the specified limit given by the manufacturer, or because of any internal changes which leads to increase in battery temperature. The design is expected to be simple, reliable and efficient.

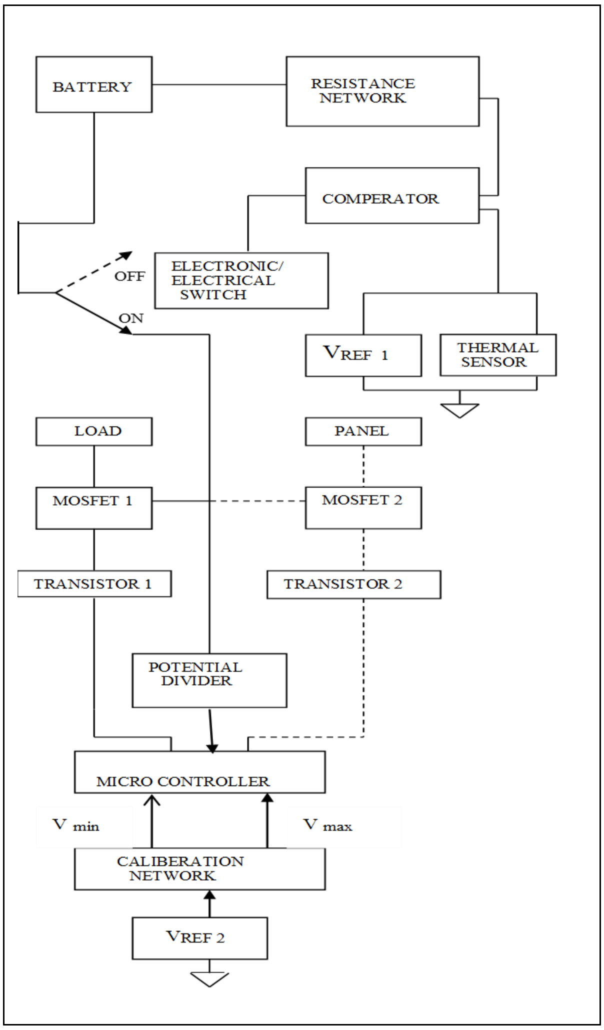

Figure 3: Block diagram of the Charge Controller.

The essential components required for the circuit of the charge controller and their brief introduction is presented below:

1) Microcontroller

Microcontroller is an inexpensive single chip microcomputer. It essentially comprises of a Central Processing Unit (CPU), memory devices (RAM, ROM, EEPROM), input/output lines (I/O line), series and parallel ports, timer and other built- in peripherals such as analog-to-digital (A/D) and digital to-analog (D/A) convertors. The microcontroller observes the status of the solar panel and battery, and takes the decision in accordance with the program burned in it.

First microcontroller was INTEL 8048 released in 1976. Today large variety of microcontroller exits in the market. Amongst them are versatile microcontroller chip called PIC chips from Microchip Technologies [13]. Microchip manufactures different family of microcontroller called PIC e.g. PIC 10, PIC 12, PIC 14, PIC 16 and PIC 18. Some are basic low memory type, some has A/D converter and even PMW built-in. e.g., PIC 12F675 or PIC16F676 can be used. They are small, cheap and have A/D conversion and are easily available in the Indian market. PIC12F675 is an 8 pin and PIC16F676 is a 14-pin microcontroller.

2) Power MOSFET

Power metal-oxide-semiconductor field effect transistor (MOSFETs) simplify circuitry because they are voltage-controlled devices and require only very small instantaneous currents from the signal source. They are rugged and have switching times less than 100 nanoseconds at high current levels. The gain and response time characteristics is stable over a wide range of temperature e.g., HEXFET (a trademark for International Rectifier power MOSFETs) offers a very low on-state resistance combined with high transconductance and diode recovery capabilities [14]. They are well suited for applications such as switching or amplification of the electronic signals. MOSFETs ensures that in conditions of low battery or overload, load is cut off.

3) Transistor

Transistors are required to switch the MOSFETs and provide proper insolation between MOSFET and microcontroller. The power requirement of the transistor is small and hence BC547 or equivalent transistor can be used.

V. Working

The working of the complete circuit can be divided into two parts-A and B, as explained below:

A) The working of the circuit can be initialized by setting two voltages V_{min} and V_{max} using variable power supply and calibration network. Battery voltage is also given to the microcontroller. The microcontroller will convert those three voltages and compare the battery voltage V_B to V_{min} and V_{max}, and will take the action in accordance with the proposed input logic.

This is further explained using an example of a 12 V battery connected to 32Watt solar panel.

Let V_{min} = 10.5V and V_{max} = 13.0V

1) If V_B < 10.5V, microcontroller will take the action in accordance with the proposed logic which in turn will enable the series combination of transistor and MOSFET to connect the battery with panel, disconnecting load from it.

2) If V_B > 13.0V, microcontroller will connect the battery to load, disconnecting panel from it.

3) If 10.5V < V_B < 13.0V, battery will be in the float mode in which it will get power from the panel during day time and deliver current to the load simultaneously. However, it will not discharge during night due to the presence of blocking diode.

B) If the battery temperature increases beyond the specified temperature given by the manufacturer, then battery will be cut-off from the rest of the circuit to avoid damage to the battery and to the circuit. This cut-off action is accomplished as follows:

The comparator compares the battery voltage (through a potential divider network) to a reference voltage. The comparison point is offset by the thermal sensor. When the temperature of the battery is below the specified maximum temperature, output of the comparator will be high which will make the switch ‘ON’ thereby connecting the battery to the rest of the circuit. As the temperature of the battery increases beyond the specified maximum temperature, thermal sensor will make the reference voltage go low and the output of the comparator will be low which will ‘OFF’ the switch and battery will be disconnected from the rest of the circuit.

VI. Applications

Following is some of the fields of applications of Charge controller:

The street lighting system use compact fluorescent lamp (CFL). Since CFL has an efficiency of 50-60 lumens/watt over the General Lighting Service (GLS) incandescent filament lamp (the ordinary household electric bulb) with an efficiency of about 10-14 lumens/watt. The CFL is basically a gas discharge tube and therefore requires high voltage of the order of hundreds of volts to start glowing. For this reason, an oscillator circuit with high output voltage and required power, to operate the tube has to be provided. This also must have high efficiency (say > 80%). The proposed charge regulator besides preventing the battery from getting either overcharged or undercharged may be used to control the switching of the oscillator which in-turn drives the CFL [15]. The ballast in this case, a capacitor, will ensure that excessive current does not flow through the lamp and thus provides the lamp's life.

Some other applications include SPV powered home system, SPV powered traffic control systems, SPV powered communication systems in rural areas, SPV hybrid systems e.g., PV-diesel based on batteries and Solar battery charging stations to charge batteries e.g., rickshaw batteries [11].

VII. Conclusion

This paper has discussed the importance of charge regulation between the SPV array & battery bank to reduce mismatch losses. Different types of charge regulators their functionality have been reviewed for their suitability in real working conditions. The design aspects of a microcontroller-based charge regulator are presented. The presented charge regulator can tolerate the changes in battery temperature. The explicit feature of the proposed design for the charge controller is float voltage adjustment and automatic cut off of the battery from rest of the circuitry in case of the abnormal increase in temperature of the battery. The proposed charge regulator would be useful in many applications.

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